

Incidence-based Estimates of Healthy Life Expectancy for the United Kingdom: Coherence between Transition Probabilities and Aggregate Life Tables*

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Abstract

Will the United Kingdom's ageing population be fit and independent, or suffer from greater chronic ill health? Healthy life expectancy is commonly used to assess this: it is an estimate of how many years are lived in good health over the lifespan. This paper examines a means of generating estimates of healthy and unhealthy life expectancy consistent with exogenous population mortality data. The method takes population transition matrices and adjusts these in a statistically coherent way so as to render them consistent with aggregate life tables. It is applied to estimates of healthy life expectancy for the United Kingdom.

Keywords: Healthy Life Expectancy, Least-squares Adjustment, Health State Transitions

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1 Introduction

While it is plain that life expectancy has increased considerably over the last thirty years or so in many advanced countries, it is much less clear how healthy life expectancy has developed. Questions have therefore arisen about the quality of life. Are we living longer but in worse health? Are the increases in life expectancy at older ages because we are keeping sick or disabled people alive longer or because we are saving people from death but leaving them in states of disability? These are important questions both for individuals and also for government policies on social and health services provision for the elderly.

A shift in emphasis, from increasing survival to improving both the length and quality of people's lives, has led to a greater policy interest in the United Kingdom, and indeed in Europe as a whole in summary measures of population health. The government projects that the overall number and proportion of older people in the United Kingdom will rise significantly in the coming decades (?). However, there is a debate over whether these people will live longer, healthier lives, longer but more disabled lives, or something in between. The UK Treasury's long-term projections of the costs of an ageing population assume that the proportion of life spent in long-term care will remain constant but acknowledge that this is a cautious assumption and do not rule out an expansion of morbidity for the United Kingdom (?).

A crucial question therefore is whether the proportion of life spent in disability is expanding or decreasing. Existing data can be used to support either case. While there have been clear rises in overall life expectancy over time, there are concerns that not all years gained are in good health and that the proportion of extra years lived are being spent in ill-health (? and ?). Therefore, the general consensus view in the academic community seems to be that these trends reflect increased years of mild disability, and a decline in severe disability (? and ?).

Existing calculations of healthy life expectancy are compiled from the proportion of people reporting different health states (Sullivan's method)- see appendix A for a comprehensive outline of Sullivan's method and its uses. Health states of old people may reflect damage done in the past- such as injuries sustained by soldiers and civilians during the Second World War. They may therefore be a poor reflection of the risks of poor health faced by young people. ? therefore argues that healthy life expectancy should be calculated from the incidence of poor health rather than its prevalence. In terms of acceptability, the fact that transitions explicitly include return from poor to better states is important. This enables a distinction to be made between a recurrent health condition which allows for recovery, and one of steady decline to death. Estimates of transition rates can be used for the prediction of lifetime risk to individuals

of particular states of ill-health, whereas prevalence based measures cannot do this.

In order to produce measures of healthy life expectancy on this basis, information is needed on transition matrices between different health states. Such information may be available from household panel surveys such as the European Community Household Panel (ECHP), carried out in the fifteen countries of the pre-2005 European Union between 1994 and 2001. However, such surveys are typically conducted on relatively small populations, and, without further attention, the estimates of healthy and unhealthy life expectancy generated by them are unlikely to be consistent with life tables constructed from population mortality data.

In this paper we draw on a study of annual probabilities of transition between health states by ?. We describe a means of generating estimates of healthy and unhealthy life expectancy consistent with exogenous population mortality data. The method takes population transition matrices estimated from the ordered probit equations in ? and adjusts these in a statistically coherent way so as to render the transition matrices consistent with the mortality data. It is applied to estimates of healthy life expectancy for the United Kingdom.

Since, health expectancy is a complex, multi-faceted concept, this paper essentially aims to analyse the dynamics of health relating to the transition of health states in the ECHP data. This paper answers the following two questions. First, what the probability that an individual will be in the same health state next year, be free of disability, be in worse health or be dead? Secondly, what is the expected time spent in each health state given that an individual is initially in a given health category?

2 Data and Methodology

2.1 The ECHP

This paper draws on the results of ? presented in appendix B. They make use of the ECHP, the major innovative attempt at a harmonised household (longitudinal) panel across the member states of the European Union. The ECHP is essentially a standardised multi-purpose annual longitudinal survey carried out between 1994 (wave 1) to 2001 (wave 8) on each member state. Three characteristics make the ECHP a unique source of information. These are (i) its multi-dimensional coverage of a range of topics simultaneously; (ii) a standardised methodology and procedures yielding comparable information across countries; and (iii) a longitudinal or panel design in which information on the same set of households and persons is gathered to study changes over time at the micro level.

? modelled the annual probabilities of transition between health states for the EU

member states including the United Kingdom using pooled ordered probit equations from the ECHP. Separate formulae were used for people above and below 65. Here we focus on the results for the United Kingdom.

2.2 Choice of Health Measures

From the range of health status variables available in the ECHP, two in particular were chosen. These are self-assessed health (SAH) (indicator PiH001) and the existence of a chronic health or disability problem (PiH002) combined with the degree of hampering health (HH) (PiH003).

2.2.1 Self-Assessed Health

In the ECHP users' database (UDB), self-assessed health (SAH) is asked as 'Please think back over the last 12 months about how your health has been. Compared to people of your own age, would you say that your health has on the whole been (i) excellent; (ii) good; (iii) fair; (iv) bad; or (v) very bad? (PiH001)'. ? took the decision, after considering the responses to PiH001 to combine 'bad' and 'very bad' health states. Although this may remove some potential information, it avoids a serious problem arising from the small numbers found in the worst category in even the highest age groups. Therefore we can think of death as a fifth state ranked below bad/very bad health.

2.2.2 Hampering Health Condition

The second measure of health is derived from the hampering health (HH) condition. This indicator derives from two questions. Firstly, 'Do you have any chronic physical or mental health problem, illness or disability? (PiH002)' and secondly, 'Are you hampered in your daily activities by this physical or mental health problem, illness or disability? (PiH003)'. The three possible resulting states are (i) no such condition or a chronic condition, but not hampered; (ii) hampered to some extent; or (iii) hampered severely. Death is, as mentioned previously, an additional state.

? ran into several serious problems concerning the consistency and interpretation of the British data regarding health, which are supplied to the ECHP as 'clone' data from the British Household Panel Survey (BHPS). A trial of three waves of parallel household surveys, national and the ECHP, showed this was too much of a strain, with high non-response rates, and as a result the sample size was reduced by about a half from the fourth wave forwards. A conclusion from this is that for HH, the category 'to some extent' hampered was only used in the parallel

survey and then again in just wave 6 of the BHPS. The effect of this seriously changed the distribution. In consequence ? made a decision to limit the analysis of the UK sample by omitting the ‘to some extent’ category, and on the evidence of the UK parallel survey, results for this health definition will be incompatible with other countries. As a result, only two health states were examined for the HH measure of healthy life, namely, ‘no hampered condition’ and ‘hampered severely’ with the additional absorbing state, death.

It is widely recognised that this indicator is less prone to subjectivity than SAH and more immediately connected with disability, dependency and a need for long-term care (? and ?). The European Commission considers this to be an indicator for disability (?). Also ? recently surveyed a variety of questions on disability for the UK Department of Work and Pensions, and noted that a similar census question which first made its appearance in 1991 had been validated as a disability measure.

3 Initial Transition Matrix Estimates

For both of the domains distinguished, therefore, an ordered ranking was generated running from the most healthiest state, ‘very good’ for SAH, and ‘not hampered to any degree’ for HH, to the least favourable value, i.e. death, the only absorbing state. The fact that the health states can be ranked, a natural way to estimate transition probabilities as a function of age and gender is by fitting an ordered probit model. Here we draw on the models estimated by ? as mentioned above (see also ?), one for men and women aged under sixty-five and the other for those aged sixty-five or older (Appendix B presents estimates of the ordered probit equations for the United Kingdom derived from ?).

The underlying probit function applied follows ? and was used for example by ? in a similar analysis of health transitions with the ECHP. A modelling approach to estimating transitions that makes use of the latent variable specification can be written as

$$h_i^* = \beta_k + x_i' \cdot \gamma_k + e_i \quad (1)$$

where h_i^* is some underlying continuous latent variable for the i th individual that underlies reported SAH and HH; β_k is a constant depending on the starting health state k ; e_i denotes a random, independently distributed component following a normal $N(0,1)$ distribution. The variable x_i is a vector of covariates including age and gender coefficients and γ_k a vector of parameters, which again are assumed specific to the starting health state. If there is a general trend, ? suggest that gender coefficients, applying to women, tend to be positive at initial good states of health, negative at bad states of health. This implies that women are more likely to

decline from good states of health, but men are more likely to decline or die once in a bad state of health. ? have also argued that it is plausible to drop the time-dependence t in the present case, and pool across waves 1 to 8 (i.e. 1994-2001), since there is no discernible evidence of trends in the transitions. Since h_i^* is not observed, ? in effect partition it into the observed states, h_i , by a set of unknown cut points, α , (or threshold parameters), such that

$$h_i = j \text{ if } \alpha_{j,k} < h_i^* \leq \alpha_{j+1,k}, \quad j = 1, \dots, n \quad (2)$$

where $\alpha_0 = -\infty$; $\alpha_j \leq \alpha_{j+1}$ and $\alpha_J = \infty$. Thus each observed health state corresponds to a value range within the unobserved, latent distribution for health, such that the entire range of the distribution is covered by one and only one health state. The transition probabilities derive from the conditional distribution of $h_{i,t+1}$ given the state k at time t :

$$P(h_{i,t+1} = j \mid k) = \Phi(\alpha_{j+1,k} - \beta_k) - \Phi(\alpha_{j,k} - \beta_k) \quad (3)$$

where Φ denotes the cumulative standardised normal distribution.

From these probit equations we calculate transition matrices as a function of age and gender. We denote these \mathbf{M}_0 to \mathbf{M}_{99} . For an initial population vector \mathbf{x}_i whose j th element, x_{ij} shows the number of people in health state j on their i th birthday. It then follows that $\mathbf{x}_{i+1} = \mathbf{M}_i \mathbf{x}_i$. If we denote by \mathbf{i} a vector of 1s with length equal to the number of health states, then from an initial population \mathbf{x}_0 the proportion surviving to their $i + 1$ st birthday is given as

$$s_i = \frac{\mathbf{i}' \prod_{k=0}^{i-1} \mathbf{M}_k \mathbf{x}_0}{\mathbf{i}' \mathbf{x}_0} \quad (4)$$

while we denote the proportion surviving to their i th birthday in the life table as s_i^* . Given our initial estimates of the transition matrices, we wish to find new transition matrices, \mathbf{M}_k^* such that

$$s_i^* = \frac{\mathbf{i}' \prod_{k=0}^{i-1} \mathbf{M}_k^* \mathbf{x}_0}{\mathbf{i}' \mathbf{x}_0} \quad (5)$$

where the \mathbf{M}_k^* are reasonably close to the initial estimates \mathbf{M}_k . It is obvious that s_i can be driven to s_i^* only by adjusting the transition matrices \mathbf{M}_k where $k \leq i - 1$. But an adjustment to one of these matrices has implications for s_m for all $m > i$. Thus, although it is obviously possible to address the problem sequentially, it is unlikely that sequential adjustment will offer the most satisfactory solution.

4 A Least-Squares Approach

Following from ? who first proposed the use of a proportional fitting procedure to estimate cell probabilities in a contingency table subject to certain marginal constraints, we set out here

a least-squares solution to the problem of adjusting the transition matrices in order for them to be consistent with exogenous mortality data. Our approach however differs somewhat from the original methods of ?, and that later extended by ?, in that while they concentrated on a linear model in which the solution is derived exactly, the constraints that we face are non-linear functions of the transition probabilities.

We denote by the vector \mathbf{n}_k the vector constructed from the four columns of transition matrix \mathbf{M}_k stacked in order and further consider the vector

$$\mathbf{n}^0 = \begin{bmatrix} \mathbf{n}_0 \\ \dots \\ \mathbf{n}_k \\ \dots \\ \mathbf{n}_{99} \end{bmatrix} \quad (6)$$

We write the vector of survival proportions generated by the vector \mathbf{n} as $\mathbf{s}(\mathbf{n})$ with its i th element $s_i(\mathbf{n}) = s_i$ and the observed survival proportions as \mathbf{s}^* . We then aim to find $\mathbf{n}^* = \mathbf{n}^0 + \Delta\mathbf{n}$ to minimise

$$\frac{1}{2} \Delta\mathbf{n}' \mathbf{V}^{-1} \Delta\mathbf{n} + \lambda \{ \mathbf{s}^* - \mathbf{s}(\mathbf{n}^0 + \Delta\mathbf{n}) \} \quad (7)$$

where \mathbf{V}^{-1} is a weighting matrix with V_{ij} indicating the i th row and j th column of \mathbf{V} with n_i the i th element of \mathbf{n}^0 . We set $V_{ii} = n_i^2$ and $V_{ij} = 0$ ($i \neq j$). Differentiating with respect to the elements of \mathbf{n}

$$\mathbf{V}^{-1} \Delta\mathbf{n} - \left(\frac{\partial \mathbf{s}}{\partial \mathbf{n}} \right)' \lambda = \mathbf{0} \quad (8)$$

where $\frac{\partial \mathbf{s}}{\partial \mathbf{n}}$ denotes a matrix whose i th row and j th column consists of $\frac{\partial s_i}{\partial n_j}$. This gives

$$\Delta\mathbf{n} = \mathbf{V} \left(\frac{\partial \mathbf{s}}{\partial \mathbf{n}} \right)' \lambda \quad (9)$$

We also note that by applying a Taylor series expansion we have

$$\mathbf{s}^* - \mathbf{s}(\mathbf{n}^0 + \Delta\mathbf{n}) \cong \mathbf{s}^* - \mathbf{s}(\mathbf{n}^0) - \left(\frac{\partial \mathbf{s}}{\partial \mathbf{n}} \Big|_{\mathbf{n}^0} \right) \Delta\mathbf{n} \quad (10)$$

Given that

$$\mathbf{s}^* - \mathbf{s}(\mathbf{n}^0) - \left(\frac{\partial \mathbf{s}}{\partial \mathbf{n}} \Big|_{\mathbf{n}^0} \right) \Delta\mathbf{n} \cong \mathbf{0} \quad (11)$$

The exogenous survival rates will be approximately delivered if

$$\mathbf{s}^* - \mathbf{s}(\mathbf{n}^0) \cong \left(\frac{\partial \mathbf{s}}{\partial \mathbf{n}} \Big|_{\mathbf{n}^0} \right) \Delta\mathbf{n} \quad (12)$$

We then set $\frac{\partial \mathbf{s}}{\partial \mathbf{n}}|_{\mathbf{n}^0} = \mathbf{S}_0$ and $\lambda_0 = \{\mathbf{S}_0 \mathbf{V} \mathbf{S}_0'\}^{-1} (\mathbf{s}^* - \mathbf{s}(\mathbf{n}_0))$. Therefore

$$\Delta \mathbf{n}_0 = \mathbf{V} \mathbf{S}_0' \{\mathbf{S}_0 \mathbf{V} \mathbf{S}_0'\}^{-1} (\mathbf{s}^* - \mathbf{s}(\mathbf{n}_0)) \quad (13)$$

This finalises the first stage of the iteration process.

We now put $\mathbf{n}^1 = \mathbf{n}^0 + \Delta \mathbf{n}^0$ and seek to find a vector $\Delta \mathbf{n}^1$ to minimise

$$\frac{1}{2} (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1)' \mathbf{V}^{-1} (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1) + \lambda \{\mathbf{s}^* - \mathbf{s}(\mathbf{n}^0 + \Delta \mathbf{n}^0 + \Delta \mathbf{n}^1)\} \quad (14)$$

Thus, with $\frac{\partial \mathbf{s}}{\partial \mathbf{n}}|_{\mathbf{n}^1} = \mathbf{S}_1$. We then have

$$\mathbf{V}^{-1} (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1) - \mathbf{S}_1' \lambda = 0 \quad (15)$$

and approximately

$$\mathbf{s}^* - \mathbf{s}(\mathbf{n}^1) \cong \mathbf{S}_1 \Delta \mathbf{n}^1 \quad (16)$$

This then yields

$$\mathbf{S}_1 (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1) = \mathbf{S}_1 \mathbf{V} \mathbf{S}_1' \lambda \quad (17)$$

whence we have

$$(\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1) = \mathbf{V} \mathbf{S}_1' \{\mathbf{S}_1 \mathbf{V} \mathbf{S}_1'\}^{-1} \{\mathbf{S}_1 \Delta \mathbf{n}^0 + \mathbf{s}^* - \mathbf{s}(\mathbf{n}^1)\} \quad (18)$$

A further increment $\Delta \mathbf{n}^2$ is chosen to satisfy

$$\mathbf{V}^{-1} (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1 + \Delta \mathbf{n}^2) - \mathbf{S}_2' \lambda = 0 \quad (19)$$

and approximately

$$\mathbf{s}^* - \mathbf{s}(\mathbf{n}^2) \cong \mathbf{S}_2 \Delta \mathbf{n}^2 \quad (20)$$

giving

$$(\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1 + \Delta \mathbf{n}^2) = \mathbf{V} \mathbf{S}_2' \{\mathbf{S}_2 \mathbf{V} \mathbf{S}_2'\}^{-1} \{\mathbf{S}_2 (\Delta \mathbf{n}^0 + \Delta \mathbf{n}^1) + \mathbf{s}^* - \mathbf{s}(\mathbf{n}^2)\} \quad (21)$$

A recursive algorithm can be constructed

$$\Delta \mathbf{n}^j = \mathbf{V} \mathbf{S}_j' \{\mathbf{S}_j \mathbf{V} \mathbf{S}_j'\}^{-1} \left\{ \mathbf{S}_j \sum_{i=0}^{j-1} \Delta \mathbf{n}^i + \mathbf{s}^* - \mathbf{s}(\mathbf{n}^j) \right\} - \sum_{i=0}^{j-1} \Delta \mathbf{n}^i \quad (22)$$

with $\mathbf{n}^j = \mathbf{n}^0 + \sum_{i=0}^{j-1} \Delta \mathbf{n}^i$ and subsequently, for any j $\frac{\partial \mathbf{s}}{\partial \mathbf{n}}|_{\mathbf{n}^j} = \mathbf{S}_j$. Since the least-squares minimand is evaluated afresh at each value of \mathbf{n}^j an optimum is reached as $\Delta \mathbf{n}^j$ converges towards zero and the iterations can be stopped when it is close to zero as defined by an appropriate tolerance level. The adjusted vector \mathbf{n}^j provides the transition matrices at the j th iteration and when these are consistent with observed survival rates, so too will be the healthy and unhealthy life expectancies derived from them.

5 Application to the United Kingdom

Healthy life expectancy is given as the probability of being in either a ‘very good’ or ‘good’ state given the condition of being in a ‘very good’ health state to begin with for SAH. For HH, healthy life expectancy is simply given as the probability of being in a ‘none/slight’ state conditional on the probability of being in a ‘none/slight’ state initially. The table below provides estimates of healthy and unhealthy life expectancy using both SAH and HH for men and women at age sixty-five in the United Kingdom averaged between the period 1994 (wave 1) to 2001 (wave 8). The unadjusted estimates are derived from the transition probabilities computed with the ordered probit equations prior to the alignment having taken place. The data published by the Office of National Statistics (ONS) are derived from interim life tables based on three adjacent years provided by the Government Actuary’s Department. The life tables from ? are available for three year windows in which the central year was chosen as the average, for example, the year 1994 was computed from the window years 1993 to 1995.

		Unadjusted Estimates			ONS Estimates
		Life expectancy	Healthy life expectancy		Life expectancy
Years		Years	Years	% of lifetime in healthy life	Years
Men	SAH	16.4	9.6	58.5	15.2
Women	SAH	14.9	9.2	61.7	18.5
Men	HH	17.3	12.0	69.3	15.2
Women	HH	15.6	11.0	70.5	18.5

Table 1: Life expectancy and healthy life expectancy estimates using both SAH and HH at age 65 for men and women between 1994 and 2001 in the United Kingdom calculated from the transition probabilities

Table 1 clearly sets out the problem. Whilst the transition probabilities were pooled over the eight waves of the ECHP and thus life expectancy using the unadjusted estimates is taken as an average over the eight years (i.e. 1994-2001), life expectancy from the official data were computed by taking the average from each wave for the sample year of the ECHP. Therefore, life expectancy calculated from the transition probabilities given by the unadjusted estimates suggests an apparent discrepancy with the official data. The clear conclusion that can be identified from table 1 is that the unadjusted estimates do not appear to deliver the results of life expectancy provided by the official data, casting doubt on the use of the associated estimates of healthy life expectancy.

By using the alignment process derived by means of an least-squares approach (as discussed in section 4), healthy life expectancy consistent with official life expectancy data was calculated for a time-series of eight years between 1994-2001, which are given in tables 2 and 3 below for men and women at age sixty-five in the United Kingdom. The results depend, of course, on the assumed mix of health states at age sixty-five. We have generated this using the adjusted transition probabilities from birth. The health state mix at age sixty-five is insensitive to that used at birth to start the process. ONS estimates, based on Sullivan's method, for the same period are also presented in order to give a comparison with our alignment results. As one would expect from these tables, both measures of healthy life expectancy tend to increase steadily with time for men and women. The implementation of the adjustment process has meant, of course, that life expectancy figures are identical to the ONS estimates since they are derived from mortality tables provided by the Government Actuary's Department projections which are taken for cohorts aged sixty-five between 1981 and 2054 (?).

	Self-Assessed Health - SAH			Hampering Health - HH			ONS Estimates		
	Life expectancy	Healthy life expectancy		Life expectancy	Healthy life expectancy		Life expectancy	Healthy life expectancy	
Year	Years	Years	% of lifetime in healthy life	Years	Years	% of lifetime in healthy life	Years	Years	% of lifetime in healthy life
1994	14.5	8.9	61.4	14.5	10.4	71.7	14.5	11.0	75.9
1995	14.7	8.9	60.5	14.7	10.5	71.4	14.7	11.3	76.9
1996	14.8	9.0	60.8	14.8	10.6	71.6	14.8	...	...
1997	15.0	9.1	60.7	15.0	10.7	71.3	15.0	11.7	78.0
1998	15.2	9.2	60.5	15.2	10.8	71.1	15.2	...	...
1999	15.4	9.3	60.4	15.5	11.0	71.0	15.4	11.5	74.7
2000	15.7	9.5	60.5	15.7	11.1	70.7	15.7	...	...
2001	15.9	9.6	60.4	15.9	11.2	70.4	15.9	11.6	73.0
Increase from 1994 to 2001	1.4	0.7	-1.0	1.4	0.9	-1.3	1.4	0.6	-2.9

Table 2: Life expectancy and healthy life expectancy estimates at age 65 for men between 1994 and 2001 in the United Kingdom

	Self-Assessed Health - SAH			Hampering Health - HH			ONS Estimates		
	Life expectancy	Healthy life expectancy		Life expectancy	Healthy life expectancy		Life expectancy	Healthy life expectancy	
Year	Years	Years	% of lifetime in healthy life	Years	Years	% of lifetime in healthy life	Years	Years	% of lifetime in healthy life
1994	18.1	11.3	62.4	18.1	12.9	71.3	18.1	12.9	71.3
1995	18.2	11.3	62.1	18.2	12.9	70.9	18.2	13.0	71.4
1996	18.3	11.4	62.3	18.3	13.0	71.0	18.3	...	...
1997	18.4	11.4	62.0	18.4	13.0	70.7	18.4	13.1	71.2
1998	18.5	11.4	61.6	18.5	13.1	70.8	18.5	...	...
1999	18.6	11.5	61.8	18.6	13.2	71.0	18.6	13.1	70.4
2000	18.8	11.6	61.7	18.8	13.4	71.3	18.8	...	...
2001	19.0	11.7	61.6	19.0	13.4	70.5	19.0	13.2	69.5
Increase from 1994 to 2001	0.9	0.4	-0.8	0.9	0.4	-0.8	0.9	0.3	-1.8

Table 3: Life expectancy and healthy life expectancy estimates at age 65 for women between 1994 and 2001 in the United Kingdom

The last row of tables 2 and 3 demonstrates how life expectancy and healthy life expectancy estimates have changed over the eight year time span. It appears to be the case that HH estimates of healthy life expectancy are markedly higher than those given by SAH estimates for both men and women. This could be due to a number of reasons, for instance, the health categories of the two healthy life measures could be interpreted differently by different individuals and hence therefore more people stating a healthy state of wellbeing for the HH estimate. In other words, since the HH definition of healthy life expectancy is much more wider (i.e. less health categories and thus more chance of being placed in a healthy state), so that many conditions count as healthy, relative to the much narrower SAH definition where many people are classed as unhealthy, healthy life expectancy using HH may give the impression that the time spent in healthy life will be relatively long, and will tend towards total life expectancy if very few people are counted as unhealthy. As an aside, it is interesting to note that though the HH estimates of healthy life expectancy are higher than that given by the SAH measure, the percentage of time spent in healthy life for HH tends to be decreasing at a higher rate than that of SAH for both men and women.

In general, although life expectancy has risen for both men and women using both measures of healthy life, the percentage of the lifetime spent in ill-health tends to be increasing for both men and women. This suggests that people are now living to ages in which they are more likely to experience chronic diseases and disability, supporting the expansion of morbidity hypothesis whereby as life expectancy increases, older people become more vulnerable to chronic diseases and spend more time in ill-health and thus a higher proportion of people with health problems survive to an advanced age (? and ?).

The last three columns present data published by the ONS of life expectancy and healthy life expectancy between 1994 and 2001. The ONS defines healthy life expectancy (HLE) from the age-specific prevalence (proportions) of the population (rather than in incidence terms) in healthy and unhealthy conditions and age-specific mortality information. Data for 1996, 1998 and 2000 were not published by the Statistical Office.

The method applied (discussed in ?) uses the General Household Survey (GHS) to provide estimates of healthy life expectancy using the Sullivan method. The GHS asks a similar question to that of the SAH measure used in the ECHP; ‘Over the last 12 mths would you say your health has on the whole been good, fairly good or not good?’. From tables 2 and 3 it appears that the ONS estimates of healthy life expectancy are somewhat higher for both men and women relative to our measures, except for HH for women, in which our estimates are slightly higher. One explanation of this discrepancy between our healthy life estimates and

the ONS data could well be due to the fact that our estimates are based on incidence rates (i.e. represent current health conditions and can help predict future health care requirements) whilst ONS figures are more prevalence based (i.e. dependent on past history). Prevalence based measures may underestimate (or overestimate) health expectancy, because the prevalence of ill-health at a given age in the population reflect the past probabilities of becoming ill at each younger age (?). Moreover, while both our findings and the ONS figures tend to support an expansion in morbidity, it is clear that our results suggest a slight increase in healthy life expectancy relative to the ONS estimates based on the Sullivan method.

In sum, one apparent conclusion from the analysis appears to be that though there is some variation in our measures of healthy life expectancy and that of ONS estimates, the alignment procedure significantly reduces the dispersion of healthy life expectancy for both men and women. This could suggest that the unadjusted results derived from the probit equations may appear to give inaccurate estimates of healthy life expectancy whilst by adjusting the transition matrices to render them statistically coherent with exogenous population mortality data tends to have produce much more precise estimates of healthy life expectancy.

6 Discussion and Conclusions

Since this paper outlines a longitudinal health study different from that performed using cross-sectional data and Sullivan’s method, this has meant we have the novel advantage of being able to take account of transitions into and out of various health states over time for the United Kingdom. This multistate approach has the advantage over Sullivan’s method of providing health expectancy estimates based on current rather than historical morbidity prevalence rates. The multistate life tables of the transition probabilities and the expected time spent in each health state also provides a clearer basis on which to predict service needs.

The results of this paper lend themselves to support the expansion of morbidity hypothesis; where the additional gains in life expectancy are spent in bad health while the number of years spent in good health remains constant. Also, our results do indeed point to a slower worsening in healthy life expectancy than the ONS estimates based on Sullivan’s method. Therefore, whilst our results and ONS estimates appear to suggest an expansion in morbidity, our findings propose an improvement in healthy life expectancy relative to the Sullivan method.

However, it has to be recalled that when using healthy life expectancy measures, such as, SAH and HH, estimates can change over time simply due to changes in individuals’ subjective perceptions rather than a true deterioration or improvement in the population’s health. Hence, since SAH and HH are subjective measures, meanings attached by respondents to the

categories may have changed over time due to medical advances. Also, both health measures differ between different subgroups of the population. Therefore account must be taken for individual’s interpretation of the different health states which may be affected by individuals age, gender and socio-economic circumstances. The same issue of perception and interpretation do not apply to total life expectancy, hence, the difference between quality and quantity health measures.

A Appendix: Estimation of Healthy Life Expectancy

The estimation of healthy life expectancy is based on the concept of a closed population within a given period of time, in this case, using the ECHP data between 1994 and 2001. Thus, this population does not account for immigration or emigration. At the end of the period in question, the population can be partitioned into those who die within the period and those who are still alive. Of those still alive, the majority are expected to be healthy, and some are expected to be unhealthy. Hence, a model can be built that measures the health status of individuals who are alive at the same time it accounts for those who die in the period in question. This section reviews the techniques used to incorporate healthy life expectancy, namely, prevalence-based life tables (Sullivan’s method) based on the prevalence of disability that is a stock that is dependent on past history) and incidence-based life tables (multistate method which can adjust to represent current health problems). Many researchers have indeed commented on the differences between the Sullivan and multistate methods (? and ?).

On the whole, experience has shown that Sullivan’s method can, generally, be recommended for its simplicity, relative accuracy, ease of interpretation and suitability for long-term trends and comparisons between populations and subgroups. Yet although most empirical research has used Sullivan’s method, its limitations are now well understood. In particular, Sullivan’s method is not suitable for detecting recent abrupt changes in trends, nor for estimating incidence rates, prognosis, or life-time risk. It is therefore better in principle to base future estimates of health care needs on the current incidence of ill-health, rather than on current prevalence. Incidence rates provide estimates of the current state of health needs, and thus offer more accurate forecast of future health care needs. Hence, the reason to apply incidence based measures here to predict precise measures of healthy life expectancy.

A.1 Sullivan’s Method

Sullivan’s method (see ? and ?) requires only a population life table (which can be constructed for a population using the observed mortality rates at each age for a given time

period) and prevalence data for the health states of interest. Such prevalence rates can be obtained readily from cross-sectional health or disability surveys carried out for a population at a point in time. Surveys of this type are carried out regularly in the United Kingdom, both at the national (? and ?) and regional level (?), and indeed across the EU member states (? and ?). Its interest lies in its simplicity, the availability of its basic data and its independence of the size and age structure of the population. The health status of a population is inherently difficult to measure because it is often defined differently among individuals, populations, cultures, and even across time periods.

The objective of the Sullivan method is essentially to calculate the expected life expectancy of groups of individuals currently at specified ages if they lived the rest of their lives experiencing the age-specific mortality rates observed for the population at a specific time. Thus the technique essentially uses the age-specific mortality to calculate the proportion of individuals alive at the beginning of an age interval that die before reaching the next age group. Hence, this technique is a powerful tool for estimating the remaining years of life that a group of individuals can expect to live once they reach a certain age. The procedure for calculating Sullivan's method is outlined below:

1. For each age/gender group obtain the life table schedules and the expectation of life for the year of interest. Then calculate

$${}_nL_x = e_x l_x - e_{x+n} l_{x+n} \quad (\text{A1})$$

where ${}_nL_x$ is the conventional life table measure of the average number of person years lived in the age interval x an $x + n$ (alternatively this may be calculated from mortality rates).

2. Obtain the ill-health rate ${}_n d_x$ in each age-group observed in a survey or census. If they are excluded, add the numbers in communal establishments catering for the sick and disabled. Calculate the average number of persons aged x to $x + n$ living without ill-health in each age/gender group as

$${}_nLWD_x = {}_nL_x(1 - {}_n d_x) \quad (\text{A2})$$

3. Calculate life expectancy without ill-health as

$$HLE_x = (\sum {}_nLWD_x) / l_x \quad (\text{A3})$$

where the summation is from age x upwards. Hence equation (A3) presents the proportion of years lived in a healthy state.

However, given the overall usefulness of the Sullivan method, it is better in principle to base future estimates on health care needs on the current incidence of ill-health, rather than on

current prevalence. Prevalence of chronic health conditions is affected only by past history in that it is seen as a stock variable reflecting past flows, rather than current health risks (?). For example, past wars may continue to affect current disablement rates, as may the past state of health care, as conditions such as polio and thalidomide illustrate. Therefore, if public health is changing, present prevalence may be a poor guide to the future. This is one reason why it is inadvisable simply to project current average age-specific expenditure rates to predict future long term care needs. Incidence is a better guide to the current state of health needs, and hence to predictions of future health. In this case though, the Sullivan health expectancy remains a meaningful indicator of the state of health at a population, rather than prediction at an individual, level.

Consequently, although Sullivan’s method fails to be a good predictor of changes in the years an individual can expect to live in healthy years, it does remain a meaningful indicator of the state of health of a population at a starting point in time. Hence, it reflects the healthy years an individual can expect to live only if current patterns of prevalences apply during an entire lifetime.

A.2 The Multistate Method

Although empirical research has mainly used Sullivan’s method of calculating healthy expectancies, the approach used here applies the multistate life table method for calculating healthy life expectancy. Multistate life table methods for calculating health expectancies were first proposed by ? and ? to take into account reversible transitions between one health state and another. This approach is theoretically attractive since it allows one to calculate health expectancies for population subgroups in a specific health state at a given age, for example, those in a ‘very good’ health state at age sixty-five, whereas the Sullivan method gives only the average health expectancy for the entire population at a given age. Hence the multistate method is based on incidence rates that represent current health conditions. The procedure therefore carried out in this study which is outlined below generalises the multistate life table, which analyses the transition from a given health state to another state or to the absorbing state, death.

The approach applied here therefore provides the critical link between information on mortality and information on the spectrum of non-fatal health experiences among the living. As an alternative to ?, where the results were divided between under sixty-five year olds and people aged sixty-five or older, an attempt was made to compute gender specific values for all age groups between 0 and 99 for each Member State.

The initial stage of our model consisted of calculating transition probabilities by constructing normal distributions from the α coefficients derived from the probit equations in ?, for each health state and for each of the two measures of health expectancy. We denote by \mathbf{M}^i the transition matrix for an individual aged i . Each element $\mathbf{M}_{j,k}^i$ shows the probability that an individual in health state k in year i will be in health state j in year $i + 1$. So the transition probabilities for each Member States are therefore given by

$$\mathbf{N}_{j,k}^1 = \mathbf{M}_{j,k}^1 \quad (\text{A4})$$

$$\mathbf{N}_{j,k}^{i+1} = \mathbf{M}_{j,k}^{i+1} \cdot \mathbf{N}_{j,k}^i \quad (\text{A5})$$

where $\mathbf{N}_{j,k}^i$ is the probability that an individual is state j conditional on him or her being in state k at birth.

The next step consisted of simply computing the expected time in each health state given that the individual was in a specific health category to begin with, as a function of age and gender. It is apparent for all the countries examined that as the age of the individual increases the expected time spent in good health deteriorates and the time spent in bad health or dying rises. It should also be noted that although the figures are presented for ages 0 to 99, the oldest age reported for any country is 91, so beyond this point figures may be of doubtful value. In order to calculate expected time spent in each of the health states, denoted by $\mathbf{Z}_{j,k}^i$, we have

$$\mathbf{Z}_{j,k}^{99} = \mathbf{M}_{j,k}^{99} \quad (\text{A6})$$

$$\mathbf{Z}_{j,k}^{99-i} = \mathbf{M}_{j,k}^{99-i} \cdot \mathbf{Z}_{j,k}^{100-i} + \mathbf{Z}_{j,k}^{100-i} \quad (\text{A7})$$

Equations (A6) and (A7) therefore provide the basis for determining the expected number of years that an individual will spend state j conditional on him or her being in state k to begin with for each men and women in the United Kingdom. In order to conclude this section it is worthwhile recalling that while the Sullivan method of calculating healthy life expectancy is based on prevalence rates, i.e. the prevalence of disability that is a stock that is dependent on past history, the multistate method applied here is based on incidence rates and thus can adjust to represent current health conditions.

B Appendix: Ordered Probit Equations used to Construct Transition Probabilities

The tables below provide estimates of health transition rates estimated from the ordered probit equations given in ? for the United Kingdom. Standard errors of coefficients are shown in brackets. * denotes coefficients (age, gender) not statistically significant (5% level). The tables also exclude admissions to a health-care institution.

(a) People under 65

Initial Health	α_1	α_2	α_3	α_4	Age (years)	Gender
Very Good	0.264 (0.045)	1.490 (0.046)	2.221 (0.055)	3.143 (0.138)	-0.001* (0.001)	0.078 (0.027)
Good	-0.779 (0.032)	1.064 (0.033)	2.097 (0.037)	3.444 (0.116)	0.002 (0.001)	0.108 (0.019)
Fair	-1.093 (0.053)	0.311 (0.050)	1.733 (0.054)	3.141 (0.085)	0.013 (0.001)	-0.002* (0.029)
Bad/Very Bad	-1.284 (0.106)	-0.246 (0.100)	0.699 (0.101)	2.880 (0.121)	0.019 (0.002)	-0.107 (0.053)

Table 4: Ordered probit formulae coefficients of transition probabilities for self-reported health (SAH) from the ECHP (all waves, pooled)

Initial Health	α_1	α_2	Age (years)	Gender
None/Slight	2.381 (0.067)	3.622 (0.080)	0.015 (0.001)	0.113 (0.037)
Severe	0.336 (0.142)	3.229 (0.187)	0.022 (0.003)	-0.217 (0.067)

Table 5: Ordered probit formulae coefficients of transition probabilities for hampering health condition (HH) from the ECHP (all waves, pooled)

(b) People 65 and over

Initial Health	α_1	α_2	α_3	α_4	Age (years)	Gender
Very Good	1.955 (0.664)	3.110 (0.658)	3.687 (0.634)	3.924 (0.614)	0.026 (0.009)	0.007* (0.078)
Good	0.515 (0.323)	2.302 (0.326)	3.220 (0.32)	3.644 (0.310)	0.023 (0.004)	0.079* (0.045)
Fair	-0.629 (0.319)	0.705 (0.318)	2.131 (0.316)	2.962 (0.308)	0.017 (0.004)	-0.076* (0.054)
Bad/Very Bad	-1.250 (0.525)	-0.285 (0.506)	0.738 (0.505)	2.244 (0.495)	0.017 (0.007)	-0.285 (0.089)

Table 6: Ordered probit formulae coefficients of transition probabilities for self-reported health (SAH) from the ECHP (all waves, pooled)

Initial Health	α_1	α_2	Age (years)	Gender
None/Slight	3.977 (0.393)	4.882 (0.386)	0.040 (0.005)	0.025* (0.063)
Severe	0.612 (0.503)	2.795 (0.497)	0.020 (0.007)	-0.210 (0.098)

Table 7: Ordered probit formulae coefficients of transition probabilities for hampering health condition (HH) from the ECHP (all waves, pooled)